Chapter 28
Atomic Physics

Quick Quizzes

Answers to Even Numbered Conceptual Questions

6. Classically, the electron can occupy any energy state. That is, all energies would be allowed. Therefore, if the electron obeyed classical mechanics, its spectrum, which originates from transitions between states, would be continuous rather than discrete.

8. The de Broglie wavelength of macroscopic objects such as a baseball moving with a typical speed such as 30 m/s is very small and impossible to measure. That is, $\lambda = h/mv$, is a very small number for macroscopic objects. We are not able to observe diffraction effects because the wavelength is much smaller than any aperture through which the object could pass.

10. In both cases the answer is yes. Recall that the ionization energy of hydrogen is 13.6 eV. The electron can absorb a photon of energy less than 13.6 eV by making a transition to some intermediate state such as one with $n = 2$. It can also absorb a photon of energy greater than 13.6 eV, but in doing so, the electron would be separated from the proton and have some residual kinetic energy.

Problem Solutions

28.1 The Balmer equation is $\frac{1}{\lambda}=R_H\left(\frac{1}{2^2}-\frac{1}{n^2}\right)$, or $\lambda=\frac{4}{R_H}\left(\frac{n^2}{n^2-4}\right)$

When $n=3$,

$$\lambda=\frac{4}{1.097\,37\times10^{7}\ \mathrm{m}^{-1}}\left(\frac{9}{9-4}\right)=6.56\times10^{-7}\ \mathrm{m}=\boxed{656\ \mathrm{nm}}$$

When $n=4$,

$$\lambda=\frac{4}{1.097\,37\times10^{7}\ \mathrm{m}^{-1}}\left(\frac{16}{16-4}\right)=4.86\times10^{-7}\ \mathrm{m}=\boxed{486\ \mathrm{nm}}$$

When $n=5$,

$$\lambda=\frac{4}{1.097\,37\times10^{7}\ \mathrm{m}^{-1}}\left(\frac{25}{25-4}\right)=4.34\times10^{-7}\ \mathrm{m}=\boxed{434\ \mathrm{nm}}$$

28.3 (a) From Coulomb's law,

$$|F|=\frac{k_e|q_1q_2|}{r^2}=\frac{\left(8.99\times10^{9}\ \mathrm{N\cdot m^2/C^2}\right)\left(1.60\times10^{-19}\ \mathrm{C}\right)^2}{\left(1.0\times10^{-10}\ \mathrm{m}\right)^2}=\boxed{2.3\times10^{-8}\ \mathrm{N}}$$

(b) The electrical potential energy is

$$PE=\frac{k_eq_1q_2}{r}=\frac{\left(8.99\times10^{9}\ \mathrm{N\cdot m^2/C^2}\right)\left(-1.60\times10^{-19}\ \mathrm{C}\right)\left(1.60\times10^{-19}\ \mathrm{C}\right)}{1.0\times10^{-10}\ \mathrm{m}}$$

$$=-2.3\times10^{-18}\ \mathrm{J}\left(\frac{1\ \mathrm{eV}}{1.60\times10^{-19}\ \mathrm{J}}\right)=\boxed{-14\ \mathrm{eV}}$$

28.7 (a) $r_n=n^2a_0$ yields $r_2=4\left(0.052\,9\ \mathrm{nm}\right)=\boxed{0.212\ \mathrm{nm}}$

(b) With the electrical force supplying the centripetal acceleration,

$$\frac{m_e v_n^2}{r_n} = \frac{k_e e^2}{r_n^2}, \text{ giving } v_n = \sqrt{\frac{k_e e^2}{m_e r_n}} \text{ and } p_n = m_e v_n = \sqrt{\frac{m_e k_e e^2}{r_n}}$$

Thus,

$$p_2 = \sqrt{\frac{m_e k_e e^2}{r_2}} = \sqrt{\frac{\left(9.11\times 10^{-31}\text{ kg}\right)\left(8.99\times 10^{9}\text{ N}\cdot\text{m}^2/\text{C}^2\right)\left(1.6\times 10^{-19}\text{ C}\right)^2}{0.212\times 10^{-9}\text{ m}}}$$

$$= \boxed{9.95\times 10^{-25}\text{ kg}\cdot\text{m/s}}$$

(c) $L_n = n\left(\frac{h}{2\pi}\right) \to L_2 = 2\left(\frac{6.63\times 10^{-34}\text{ J}\cdot\text{s}}{2\pi}\right) = \boxed{2.11\times 10^{-34}\text{ J}\cdot\text{s}}$

(d) $KE_2 = \frac{1}{2} m_e v_2^2 = \frac{p_2^2}{2m_e} = \frac{\left(9.95\times 10^{-25}\text{ kg}\cdot\text{m/s}\right)^2}{2\left(9.11\times 10^{-31}\text{ kg}\right)} = 5.44\times 10^{-19}\text{ J} = \boxed{3.40\text{ eV}}$

(e) $PE_2 = \frac{k_e(-e)e}{r_2} = -\frac{\left(8.99\times 10^{9}\text{ N}\cdot\text{m}^2/\text{C}^2\right)\left(1.60\times 10^{-19}\text{ C}\right)^2}{\left(0.212\times 10^{-9}\text{ m}\right)}$

$$= -1.09\times 10^{-18}\text{ J} = \boxed{-6.80\text{ eV}}$$

(f) $E_2 = KE_2 + PE_2 = 3.40\text{ eV} - 6.80\text{ eV} = \boxed{-3.40\text{ eV}}$

28.10 (b) From $\frac{1}{\lambda} = R_H\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$

or $\lambda = \frac{1}{R_H}\left(\frac{n_i^2 n_f^2}{n_i^2 - n_f^2}\right)$ with $n_i = 6$ and $n_f = 2$

$$\lambda = \frac{1}{1.097\,37\times 10^{7}\text{ m}^{-1}}\left[\frac{(36)(4)}{36-4}\right] = 4.10\times 10^{-7}\text{ m} = \boxed{410\text{ nm}}$$

(a) $E = \frac{hc}{\lambda} = \frac{\left(6.63\times 10^{-34}\text{ J}\cdot\text{s}\right)\left(3.00\times 10^{8}\text{ m/s}\right)}{410\times 10^{-9}\text{ m}} = 4.85\times 10^{-19}\text{ J} = \boxed{3.03\text{ eV}}$

(c) $f = \dfrac{c}{\lambda} = \dfrac{3.00\times10^{8}\ \text{m/s}}{410\times10^{-9}\ \text{m}} = \boxed{7.32\times10^{14}\ \text{Hz}}$

28.15 From $\dfrac{1}{\lambda} = R_H\left(\dfrac{1}{n_f^2} - \dfrac{1}{n_i^2}\right)$, it is seen that (for a fixed value of n_f) λ_{max} occurs when $n_i = n_f + 1$ and λ_{min} occurs when $n_i \to \infty$.

(a) For the Lyman series $(n_f = 1)$,

$$\frac{1}{\lambda_{max}} = \left(1.097\,37\times10^{7}\ \text{m}^{-1}\right)\left(\frac{1}{1^2} - \frac{1}{2^2}\right) \to \lambda_{max} = 1.22\times10^{-7}\ \text{m} = \boxed{122\ \text{nm}}$$

and

$$\frac{1}{\lambda_{min}} = \left(1.097\,37\times10^{7}\ \text{m}^{-1}\right)\left(\frac{1}{1^2} - \frac{1}{\infty}\right) \to \lambda_{min} = 9.11\times10^{-8}\ \text{m} = \boxed{91.1\ \text{nm}}$$

(b) For the Paschen series $(n_f = 3)$,

$$\frac{1}{\lambda_{max}} = \left(1.097\,37\times10^{7}\ \text{m}^{-1}\right)\left(\frac{1}{3^2} - \frac{1}{4^2}\right) \to \lambda_{max} = 1.87\times10^{-6}\ \text{m} = \boxed{1.87\times10^{3}\ \text{nm}}$$

and

$$\frac{1}{\lambda_{min}} = \left(1.097\,37\times10^{7}\ \text{m}^{-1}\right)\left(\frac{1}{3^2} - \frac{1}{\infty}\right) \to \lambda_{min} = 8.20\times10^{-7}\ \text{m} = \boxed{820\ \text{nm}}$$

28.27 (a) From $E_n = -\dfrac{Z^2(13.6\ \text{eV})}{n^2}$, $E_1 = -\dfrac{(3)^2(13.6\ \text{eV})}{(1)^2} = \boxed{-122\ \text{eV}}$

(b) Using $r_n = \dfrac{n^2 a_0}{Z}$ gives $r_1 = \dfrac{(1)^2 a_0}{3} = \dfrac{0.052\,9\times10^{-9}\ \text{m}}{3} = \boxed{1.76\times10^{-11}\ \text{m}}$

28.32 (a) For standing waves in a string fixed at both ends, $L = \frac{n\lambda}{2}$

or $\lambda = \frac{2L}{n}$. According to the de Broglie hypothesis, $p = \frac{h}{\lambda}$

Combining these expressions gives $p = mv = \boxed{\frac{nh}{2L}}$

(b) Using $E = \frac{1}{2}mv^2 = \frac{p^2}{2m}$, with *p* as found in (a) above:

$$E_n = \frac{n^2h^2}{4L^2(2m)} = \boxed{n^2E_0 \quad \text{where } E_0 = \frac{h^2}{8mL^2}}$$

28.33 In the 3*p* subshell, $n = 3$ and $\ell = 1$. The 6 possible quantum states are

$n = 3$	$\ell = 1$	$m_\ell = +1$	$m_s = \pm\frac{1}{2}$
$n = 3$	$\ell = 1$	$m_\ell = 0$	$m_s = \pm\frac{1}{2}$
$n = 3$	$\ell = 1$	$m_\ell = -1$	$m_s = \pm\frac{1}{2}$

28.34 (a) For a given value of the principle quantum number *n*, the orbital quantum number l varies from 0 to $n-1$ in integer steps. Thus, if $n = 4$, there are $\boxed{4}$ possible values of l : $l = 0, 1, 2, \text{ and } 3$

(b) For each possible value of the orbital quantum number l, the orbital magnetic quantum number m_l ranges from $-l$ to $+l$ in integer steps. When the principle quantum number is $n = 4$ and the largest allowed value of the orbital quantum number is $l = 3$, there are $\boxed{7}$ distinct possible values for m_l. These values are:

$$m_l = -3, -2, -1, 0, +1, +2, \text{ and } +3$$

28.36 (a) The electronic configuration for oxygen $(Z = 8)$ is $\boxed{1s^2\,2s^2\,2p^4}$

(b) The quantum numbers for the 8 electrons can be:

1*s* states	$n = 1$	$\ell = 0$	$m_\ell = 0$	$m_s = \pm\frac{1}{2}$
2*s* states	$n = 2$	$\ell = 0$	$m_\ell = 0$	$m_s = \pm\frac{1}{2}$
2*p* states	$n = 2$	$\ell = 1$	$m_\ell = 0$ $m_\ell = 1$	$m_s = \pm\frac{1}{2}$ $m_s = \pm\frac{1}{2}$

28.41 For nickel, $Z = 28$ and

$$E_K \approx -(Z-1)^2 \frac{13.6 \text{ eV}}{(1)^2} = -(27)^2 (13.6 \text{ eV}) = -9.91 \times 10^3 \text{ eV}$$

$$E_L \approx -(Z-3)^2 \frac{13.6 \text{ eV}}{(2)^2} = -(25)^2 \frac{(13.6 \text{ eV})}{4} = -2.13 \times 10^3 \text{ eV}$$

Thus, $E_\gamma = E_L - E_K = -2.13 \text{ keV} - (-9.91 \text{ keV}) = 7.78 \text{ keV}$

and

$$\lambda = \frac{hc}{E_\gamma} = \frac{(6.63 \times 10^{-34} \text{ J} \cdot \text{s})(3.00 \times 10^8 \text{ m/s})}{7.78 \text{ keV}(1.60 \times 10^{-16} \text{ J/keV})} = 1.60 \times 10^{-10} \text{ m} = \boxed{0.160 \text{ nm}}$$